European Transport \ Trasporti Europei (2015) Issue 59, Paper n° 4, ISSN 1825-3997

Effect of Mixed Traffic Characteristics on Saturation Flow and Passenger Car Units at Signalised Intersections

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Abstract

The present paper analyse the impact of mixed traffic behaviour on saturation flow and passenger car units (PCUs). The study precisely covers the queue release rate during the saturated green time by observing arrival rate, compositions and intersection geometry based on the traffic data extracted through videography at two major signalised intersections in Surat, India. The PCU values are derived for two-wheelers, three-wheelers and car by two different approaches namely, speed to area ratio and multiple linear regression approach. Study shows that PCU values of a particular vehicle vary with traffic situations in either peak or off peak time and queue formation at the approaches of the signalised intersections. Mixed traffic discharge rate models are developed using regression technique by relating the various traffic attributes, which shows a strong correlation between them. Dynamic saturation flow values are derived from higher arrival rate with varied width and share of two wheelers in vehicle per hour. Study shows that the saturation flow rises with the rise in arrival rate per metre width and percentage share of two-wheelers. The developed models may be useful to establish appropriate standards of saturation flow and PCUs for mixed traffic prevailing in India.

*Keywords:*signalised intersections; passenger car unit; India; mixed traffic; saturation flow

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1. Introduction

Intersections are the vital nodal points in a road network and their effectiveness of operation significantly control the entire network's performance. Several traffic control measure are used to stop conflicting movement of vehicles at the intersections. Signalised intersection is the most common form of traffic control measure used in the urban area. The analysis and design of signal system are dependent on many factors, among them saturation flow is most important. The saturation flow is defined as the maximum rate of flow that can pass through a given road space, under prevailing

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roadway and traffic conditions, during the effective green time in a signal phase. The existing saturation flow models are used to estimate flow at the specified field and traffic conditions. Traffic stream in most of the developing countries consist of a variety of vehicles which are differentiated based on their static and dynamic characteristics. The expression of saturation flow in vehicle per hour causes trouble in reckoning the flows in cases of highly heterogeneous traffic. Most of developed countries comprises of passenger cars, it has been taken as the vehicular traffic unit for the purpose of design and analysis which is widely known as 'passenger car unit' (PCU). The passenger car unit values are not fixed but vary with static and dynamic characteristics of vehicles, traffic composition and geometry of the intersection. The existing models of saturation flow reports the homogeneous traffic.Although, a few studies have been carried out on saturation flow for the mixed traffic conditions.The present study deals with the estimations of dynamic PCUs and saturation flow rates by observing several traffic attributes at the signalised intersections.

2. Literature reviews

Saturation flow is an important input parameter in the design of cycle time for traffic signals. It is the flow that can be accommodated by the lane group assuming that the green phase was displayed 100 percent of time. The saturation flow model of highway capacity manual 2010 has defined an ideal saturation flow of 1900 passenger cars/hour/lane. The model also consider the effect of several multiplicative factors, which can be computed by means of empirical formulas suggested in HCM 2010 to calculate the flow under prevailing conditions of the signalised intersection approach. The characteristics of heterogeneous traffic is significantly different from homogeneous traffic in terms of lane discipline, driver behaviour and vehicle compositions. Due to heterogeneity of traffic, it is unlikely to use the HCM Model directly because it has been developed for a homogeneous traffic conditions. Mixed traffic has varying types of vehicles: two-wheelers, motorised and non-motorised three wheelers, cars, buses, trucks, bicycles and miscellaneous types, out of them two wheelers are the major mode of transportation in most of the developing countries like India. Due to these high compositions of two-wheelers, the urban traffic behaviour is greatly different from developed nations. To analyse the effect of motorcycles on saturation flow rate, the studies conducted by (Minh and Sano, 2003) in Hanoi and Bangkok. They suggested that the effect of motorcycles is significant and should be taken into account in geometry design and operation of signalised intersections. (Anusha et al., 2013) studied the effect of two-wheelers on saturation flow at signalised intersection in Bangalore, India. They modified HCM equation by introducing an adjustment factor for two-wheelers, and concluded that the saturation flow estimated using calibrated HCM model is closer to field values. (Vien et al., 2008) studied the effect of the motorcycles travel behaviour on saturation flow rates at signalized intersections in Malaysia. They divided motorcyclists travelling through an intersection into within the flow (follow a first-in-first-out rule, travel either in front of or behind other vehicles) and outside the flow (do not follow the first-in-first-out rule). They compared the saturation flow rates observed at sites based on motorcycle inside the flow and saturation flow rates estimated using the Malaysia Highway Capacity Manual (2006) based on total volume of motorcycle, and concluded that motorcycles inside flow should be considered in the estimation of saturation flow rates.

The various factors like vehicle types, approach width, traffic mix, driver behaviour, roadside activity etc. can influence traffic behaviour and in turn the saturation flow rates. A number of studies have been done to model the effects of heterogeneous traffic on saturation flow at signalised intersection. The equation suggested by the Indian Roads Congress (IRC) to estimate saturation flow is S=525*(w), PCUs per hour, where w = width. It is valid for width from 5.5 to 18 m. (Patil et al., 2007) considered different factors like proportion of heavy vehicles, road width and proportion of turning vehicles to develop regression model to estimate saturation flow. The developed model is validated at signalised intersection in Mumbai, India. (Hossain, 2001) developed regression based saturation flow models by using the simulation results. The parameters like road width, turning proportion, percentage of heavy and non-motorized vehicles were considered. (Arasan and Vedagiri, 2006) studied the influence on saturation flow due to road width by using simulation technique. They found a positive effect on saturation flow with the width of an approach. (Arasan and Jagadeesh, 1995) suggested that the probabilistic method to be more suitable for the Indian condition to estimate saturation flow. (Radhakrishnan and Mathew, 2011) developed a saturation flow model per lane width using the different traffic parameters, by developing PCUs using optimization technique. They validated the proposed model with saturation flows collected from different locations in India.

Estimation of saturation flow requires a common platform, and this is accomplished by passenger car units. As the significant portion of the traffic in developed nations comprises of passenger cars, it has been taken as the vehicular traffic unit for the purpose of design and analysis which is widely known as ‘passenger car unit’ (PCU). But, in the mixed traffic conditions, drivers do not usually follow lane discipline and can occupy any lateral position on the road. Because of these significant differences in characteristics between the heterogeneous and homogeneous traffic, the research results based on the homogeneous situation are unlikely to give reliable results if applied in the mixed traffic conditions. (Branston and Van Zuylen, 1978) suggested a method to estimate PCUs using regression technique. In regression method, saturated green time is regressed against the number of each category of vehicles crossing the stop-line. The similar approach was used by (Arasan and Jagadeesh, 1995;Minh and Sano, 2003). (Chandra, 2004) suggested a methodology to derive dynamic PCU values based on the relative space requirement of a vehicle type compared to that of a passenger car as the basis of measure. They developed a mathematical model for PCU estimation as the ratio of the speed and projected area ratio of car and subject vehicle. A number of studies have indicated that the PCU values are not fixed but it varies with the traffic conditions. Therefore, a research is carried out for the estimation of saturation flows and passenger car units in a method suitable to the signalised intersections of mixed traffic conditions.

3. Methodology

The methodology for developing discharge rate models for signalised intersections considering the micro-level traffic aspect is suggested here. The methodology includes the observation of traffic flow parameters, intersections geometric details, derivation of PCUs, development of discharge rate models, validation of the model and derivation of saturation flow values. This study analyse the influence of mixed traffic behaviour on saturation flow rate at the signalised intersections. Traffic data were collected at two signalised intersections located in urban area of Surat, West India. The passenger car units (PCUs) values are derived for two-wheelers, three-wheelers and car in the traffic stream by two different approaches namely, speed to area ratio and multiple linear regression approach. Micro level discharge rate studies are carried out by observing different traffic parameters. The flow models are developed based on statistical significance of identified sensitive parameters. The models are validated for field conditions and saturation flow values are derived from the developed discharge rate model. These steps are detailed below.

3.1 Queue discharge data

Vehicle discharge study has been carried out at the study intersections. Videography survey is carried out at the approaches of selected intersection during the peak periods. The necessary flow data is then extracted from video. The number of vehicles discharged from an approach in the respective saturated green times provided is noted, and the discharge rate in vehicle per second of the mixed traffic is determined thereafter.

3.1.1 Derivation of passenger car units

The passenger car units (PCUs) values are derived for different types of vehicles in the traffic stream by two different approaches namely, speed to area ratio and multiple linear regression approach.Considering car as design vehicle, dynamic vehicle equivalent factor incorporates varied effect of composition and flow rate on the relative speed of the reference vehicle type, thus incorporating effect of vehicular interaction of different flow levels. The first approach is based on the speed to area ratio method. The basic concept used in this method is that the PCU value is directly proportional to the speed ratio and inversely proportional to the space occupancy ratio with respect to standard design vehicle that is car.

(Chandra, 2004) developed the concept of dynamic PCU considering the various traffic interactions and flow characteristics. The PCU for a vehicle was calculated using Eq. (2).

$$(DPCU)_m = \frac{\left(\frac{V_c}{V_m}\right)}{\left(\frac{A_c}{A_m}\right)} \quad (2)$$

Where,

$(DPCU)_m$ = Dynamic PCU for the mode ‘m’ in the traffic

m = Mode to be converted in PCU equivalent

V_C and A_C = speed and projected area of car

V_m and A_m = Speed and projected area of mode under reference.

The variable of speed ratio in the equation is a function of roadway and traffic conditions. Traffic conditions are reflected by traffic volume and composition. Any change in these conditions will affect the speed of vehicles, which is duly reflected by changes in the speed ratio. The speeds of the different categories of vehicles were measured by noting the time taken by the vehicles to traverse from a downstream to upstream stop line.

The second approach is based on multiple linear regression technique. The saturated green time is regressed against the number of each category of vehicles crossing the stop line during that time, assuming linear relationship between the variables.The common form of model is shown in Eq. (3).

$$T = a_0 + a_1 \times X_1 + a_2 \times X_2 + a_3 \times X_3 + \cdots + a_n \times X_n \quad (3)$$

Where,
T = Saturated green time (sec),
a_0= Intercept,
$a_1, a_2, a_3 \ldots a_n$= coefficient for vehicle type,
$X_1, X_2, X_3 \ldots X_n$= Number of vehicles of each category.
Then, Passenger car unit of vehicle type *i*, $PCU_i = a_i / a_{car}$

3.1.2 Discharge rate model

Based on the data collected, the discharge rate models have been developed considering effect of various attributes of the mixed traffic through regression approach. The general form of model is presented in Eq. (4). Discharge rate (veh/sec) is the *'Y'* value of the regression model, whereas the independent variables of mixed traffic attributes are from X_1 to X_n of the MLR model and $a_0$to $a_n$is the coefficients.

$$Y = a_0 + a_1 \times X_1 + a_2 \times X_2 + a_3 \times X_3 + \cdots + a_n \times X_n \quad (4)$$

The R^2 values, t-test and p-values were used to check the statistical significance of the model. Various combinationswere selected on the basis of statistical test results.

3.1.3Validation of model

The developed discharge rate model is validated by plotting calculated discharge flow versus measured discharge flow based on field conditions.

3.1.4Derivation of dynamic saturation flow rate

From the validatedmodel of discharge rate in vehicle per second, the saturation flow rates in vehicle per hour are derived by incorporating the different model attributes.

4. Data Collection

The study is carried out atRushabh and RTO Intersectionwhich considered as important urban intersections leading to major corridors of the Surat city, West India. Rushabhintersection constitutes four approaches out of which two of its approaches are 6-lane divided, whereas two of its approaches are 4-lane divided. RTO is T-intersection constitute three approaches out of which two of its approaches are 8-lane divided, whereas one of its approach is 4-lane divided. All approaches are provided with proper intersection marking and footpaths. The left turning traffic do not pose any interruption to through traffic. To study the various aspects of mixed traffic behaviour, cameras are placed at vantage points to capture every second of traffic movement at intersection approaches. Video data are collected from several intersection approaches for the queue formation and discharge operations during peak periods. The video data are than extracted by manual method. A total of 40 cycles from 4 intersection approaches is used for analysis. The highest traffic flow is observed on the selected approaches.Table 1 summarises the statistics of observed composition of vehicles which are collected from the two signalised intersections of Surat.

Table 1. Statistics of traffic composition

Statistics	*%TW*	*%Auto*	*%CAR*	*%LCV*	*%BUS*	*%HCV*
Mean	67.76	20.88	9.43	1.54	0.55	0.56
Standard deviation	9.09	7.04	3.78	1.27	0.93	0.70

4.1 Discharge rate measurements

Saturation flow is the maximum discharge rate during the saturated green time. As per the HCM, saturation flow is reciprocal of the saturation headway. In mixed traffic conditions, it is very difficult to collect the data in time headway format because of the lack of lane discipline and during subsequent discharge due to the penetration effect, narrower vehicles occupy the front of the queue and discharge in a group. So, the measurement of saturation flow as per HCM of removing first four vehicles can under estimate the flow. So far there has been no general agreement on deciding when a flow can be considered as saturated. The comparison was made between the different methods for measurement of the saturation flow by (Turner and Harahap, 1993). In the Road Note 34 method consists of taking classified counts of vehicles crossing the stop line, within the approach width, in 6 second intervals during the green and amber period of the cycle under saturated flow condition. In Webster’s method (Webster and Cobbe, 1966), in which the intervals of analyses were fixed as 5 seconds.(Hadiuzzaman et al., 2008) have used the multiple liner regression technique for classified vehicle counts.They estimated start up lost time using the road note 34 method was found to be within 2-4 seconds for mixed traffic conditions in Bangladesh. (Patil et al., 2007) have observed that the start-up lost time in Indian traffic conditions is much lower, and is considered to be 5 seconds after the green is displayed. Road Note 34 method requires data in simple classified vehicle count format, it does not allow one to calculate PCU values which are essential for saturation flow (in PCU) measurement.

Summarizing the review of past literatures, the discharge flow is measured by noting the number of vehicles of each category crossing the stop line during the saturated green time (excluding lost times) from the video. The classified count of vehicles is performed for the every directions of movement by playing a video for the number of times and each time a vehicle count of one category is performed. This process is used for the every cycle. The initial lost time was taken in the range of 2 to 4 seconds based on the previous studies of mixed traffic as stated above and the field observations. When the smaller vehicles like two-wheelers tend to bunch in front of the traffic queue, no lost time is observed.

5. Estimation of Dynamic PCU

The vehicles are grouped into three categories viz, two wheelers, three wheelers and car. The overall dimensions are shown in Table 2. Non-motorized vehicles are almost absent and as well other vehicles are negligible and hence not considered in this study.The observed mean speeds of various classes of vehicles and the corresponding standard deviations for peak and off-peak times are shown in Table 3.The dynamic PCU values have been derived by first approach as shown in Table 4.

Table 2.Dimensions of vehicles

Vehicle	*L (m)*	*B (m)*	*A (Sq.-m)*
Two-wheelers	1.9	0.72	1.37
Three-wheelers	2.6	1.4	3.64
Car	4.0	1.6	6.40

Table 3. Statistics of vehicles speed

Intersection Type	*Time Period*	*Statistics*	*Speed statistics of vehicle type*		
			Two-wheelers (kmph)	*Three-wheelers (kmph)*	*Car (kmph)*
I-01	Peak hour	Mean	19.73	17.47	16.29
		Standard Deviation	4.26	2.56	2.41
	Off-Peak hour	Mean	24.19	24.32	27.17
		Standard Deviation	6.20	5.02	6.02
I-02	Peak hour	Mean	21.56	18.72	19.15
		Standard Deviation	3.65	2.95	3.29
	Off-Peak hour	Mean	31.96	28.21	31.12
		Standard Deviation	5.85	4.21	6.27

I-01: Rushabh Intersection, I-02: RTO Intersection

Table 4. Peak and off-peak hours PCUs at signalised intersections

Intersection Type	*Time Period*	*Vehicles Type*	*Minimum*	*Maximum*	*Average*	*85^{th} Percentile*
I-01	Peak hour	Two-wheelers	0.11	0.27	0.19	0.22
		Three-wheelers	0.38	0.71	0.54	0.60
	Off-Peak hour	Two-wheelers	0.15	0.43	0.25	0.29
		Three-wheelers	0.45	0.93	0.66	0.75
I-02	Peak hour	Two-wheelers	0.13	0.31	0.19	0.21
		Three-wheelers	0.43	0.79	0.59	0.68
	Off-peak hour	Two-wheelers	0.14	0.34	0.22	0.24
		Three-wheelers	0.49	0.91	0.64	0.69

I-01: Rushabh Intersection, I-02: RTO Intersection

The saturated green time is regressed against the number two-wheelers, three-wheelers and car crossing the stop line. The study regression model is shown in Eq. (5).

$$g = 22.064 + 0.047 \times TW + 0.167 \times 3W + 0.253 \times Car, (R^2 = 0.89) \quad (5)$$

Where,
g = Signal green time (sec) with the variables, two-wheelers *(TW)*, three-wheelers *(3W)* and *car*are in numbers.

Table 5 shows the statistics obtained from the model developed.The PCU values are obtained by dividing the coefficient of TW, 3W and car by coefficient of car. The same are shown in Table 6. The computed values of Dynamic PCU can be compared with earlier model and they are within the range.

Table 5. Model regression statistics

Variables	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Adjusted R^2*
Intercept	22.065	0.667	33.069	0.000	0.87
TW	0.047	0.018	2.532	0.018	
3W	0.167	0.036	4.632	0.000	
Car	0.253	0.164	1.544	0.135	

Table 6. PCU Value of TW, 3W and Car

Type of Vehicle	*PCU*
Two-wheelers	0.18
Three-wheelers	0.66
Car	1.00

5.1 Observations on dynamic PCU values

Following are the main observations drawn from the Dynamic PCU values determined at the signalised intersections under mixed traffic conditions.

- It is observed that PCU values of a particular vehicle are not constant as they vary with traffic situations, static and dynamic characteristics of vehicles, queue formation and queue discharge behaviour at the approaches.
- PCU values for both two-wheelers and three-wheelers are lower in peak hour compared to off-peak hour traffic, as speed of the car are lower than the two-wheelers during discharging operation.
- Higher percentage of two-wheelerswere observed at the approaches of intersections. The minimum PCU value of 0.11 for two-wheelers have been observed due to seepage action by them, and that is affected on speed of the car which in turn to reduction of two-wheelers PCU.
- The presence of two-wheelers in front of the car at the queue dissipation, which matters on Dynamic PCU values.
- Dynamic PCU values for the three-wheelers are ranged between 0.38 to 0.79 during peak hour and 0.45 to 0.93 during off-peak hour.
- PCU values obtained in peak period by using regression technique for two-wheelers and three-wheelers are 0.18, 0.66 respectively which are nearer to average PCU values obtained by speed to area ratio method in peak time.
- This finding re-establishes the fact that the unified passenger car unit concept for different vehicles do not hold well for the mixed traffic condition.

The Table 7 shows thecomparison of suggested PCU values fromliteratures for the two-wheeler, three-wheelers and car at the signalised intersection. It can be perceived that the derived PCU values differ greatly from the previous studies. This is primarily attributed to the mixed traffic and the geometry of the intersection.

Table 7.Comparison of proposed PCU values with values from literature at signalised intersection

Class of Vehicles	*By Webster (1966)*	*Bhattacharya and Mandal (1980)*	*Justo and Tuladhar (1984)*	*Turner and Harahap (1993)*	*Arasan and Vedagiri (2006)*	*MHCM (2006)*	*Radhakrishnan and Mathew (2011)*	***Present Study***
Car	1.0	1.0	1.0	1.0	1.0	1.0	1.0	**1.0**
Auto Rickshaw	-	0.35	0.40	-	0.60	-	1.88	**0.60**
Scooter, Motor cycle	0.33	-	0.30	0.37	0.35	0.22	0.34	**0.20**

6. Discharge Rate Modelling

The discharge rates have been calculated by noting the numbers of different class of vehicles crossing the stop line during the saturated green time. Discharge rate (veh/sec) is the '*Y*' value of the regression model, whereas the independent variables are X_1 to X_3 of the model as shown in Eq. (6).

$$Y = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 \quad (6)$$

Where,

X_1- Width of the Approach in metre,

X_2–percentage share of two wheelers in mixed traffic (%),

X_3 - Ratio of percentage arrival rate to width of approach (%AR/W).

Eqs. (7), (8) and (9) shows the developed discharge rate models by using different combinations of geometric and traffic attributes.

$$Y_1 = -0.56 + 0.31 \times X_1,\ R^2 = 0.83 \quad (7)$$

Table 8 shows the statistics obtained from the Eq. (7).

Table 8.Discharge rate model regression statistics

Variables	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Adjusted R^2*
Intercept	- 0.559	0.28	-1.97	0.06	0.82
X_1	0.308	0.02	11.72	0.00	

$$Y_2 = -2.932 + 0.353 \times X_1 + 0.03 \times X_2,\ R^2 = 0.81 \quad (8)$$

Table 9 shows the statistics obtained from the Eq. (8).

Table 9.Discharge rate model regression statistics

Variables	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*MultipleR*	*Adjusted R^2*
Intercept	-2.93	0.85	-3.46	0.001		
X_1	0.35	0.03	10.78	0.000	0.90	0.80
X_2	0.03	0.01	3.56	0.001		

It can be observed from the Eqs. (7) and (8) that the discharge rate of mixed traffic increases with increase in the width of road and percentage share of two wheelers in the composition, because two wheelers are of smaller size and accelerate fast with high manoeuvrability.

$$Y_3 = -2.448 + 0.141 \times X_1 + 0.039 \times X_2 + 0.169 \times X_3, \quad R^2 = 0.92 \quad (9)$$

Table 10 shows the statistics obtained from the Eq. (9).

Table 10.Discharge rate model regression statistics

Variables	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Adjusted R^2*
Intercept	-2.448	0.696	-3.519	0.001	
X_1	0.141	0.034	4.174	0.000	0.91
X_2	0.039	0.007	5.353	0.000	
X_3	0.169	0.016	10.887	0.000	

Eqs. (7), (8) and (9), and Tables (8), (9) and (10)givesthe details of several combinations tried and corresponding statistics values attained.The Eq. (9) gives good R^2 value, which shows that the obtained equation is statistically stable. It can be observed from the Eq. (9) that the discharge rate of mixed traffic has positive effect with increase in the width of road, percentage share of two wheelers in the composition and the arrival rate. So,arrival rate is equally important parameter for mixed traffic. The next steps are the sensitivity analysis and validation of Eq. (9).

6.1 Sensitivity analysis

The discharge rate model (Eq. (9)) has been used here for the purpose of sensitivity analysis as typical case. Sensitivity in discharge rate per second is observed by changing one variable with keeping others variables as constant at mean value. Mean value for percentage two-wheelers, ratio of percentage arrival rate to width are 68%, 9.22 respectively.

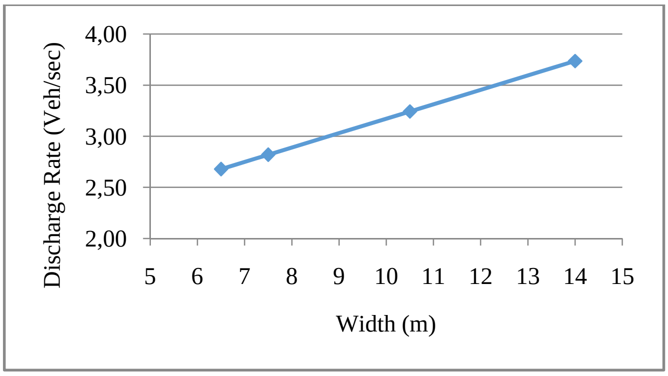

Figure 1.Approach width impact

Figure 1 shows linear relationship of discharge rate with width and it can be interpreted that discharge rate has positive effect with width of the approach.

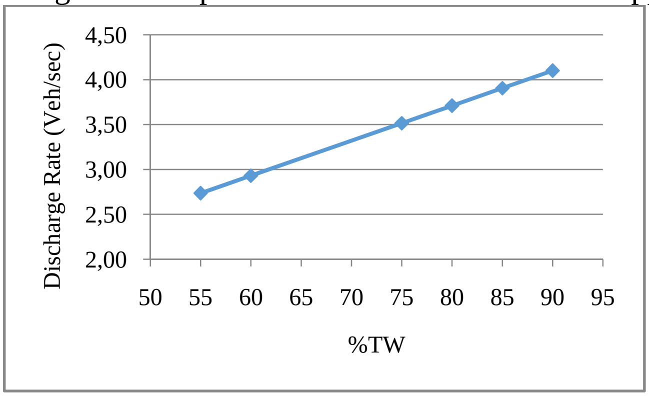

Figure 2.Impact of % share of two wheelers

In figure 2, the plot is made for width of 10.5 meter and it shows that percentage two-wheelers gives positive impact to discharge rate.

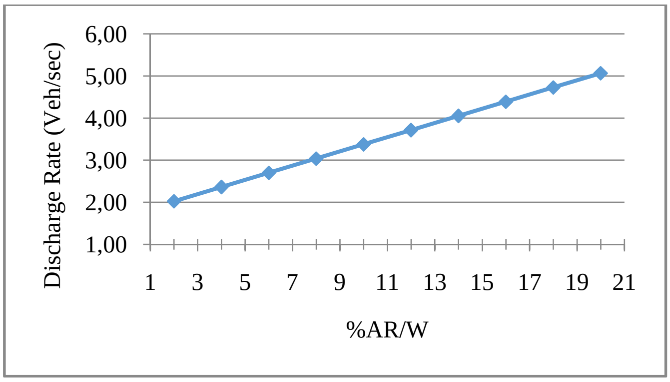

Figure 3.Impact of arrival rate

From the figure 3, it can be seen that discharge rate increases with ratio of percentage arrival rate to width. The plot between the discharge rate and ratio of percentage arrival rate to width has higher slope compared to other variables in the model, which shows significant effect by %AR/W. Minor changes in the %AR/W can cause major changes to discharge rate. Further the equation is validated using data from another set of junctions.

6.1.1 Validation

The discharge rate model is validated using the flow measured from particular intersections. For this purpose, data is collected from four intersections: three (IIM cross roads, Shahpur Char Rasta and Vijay Char Rasta) in Ahmedabad and one (Rangila Park) in Surat, India. The numbers of vehicles crossing the stop line during the saturated green timeare noted.Discharge flow is then calculated and this flow is compared to the measured discharge flow.Figure 4indicates the outcomes of validation. The plot of calculated discharge rate versusmeasured values indicates much closeness to the diagonal line. This indicates that the model can estimate discharge rate with reasonable accuracy, and can hence be used for derivation of saturation flows for different traffic attributes.

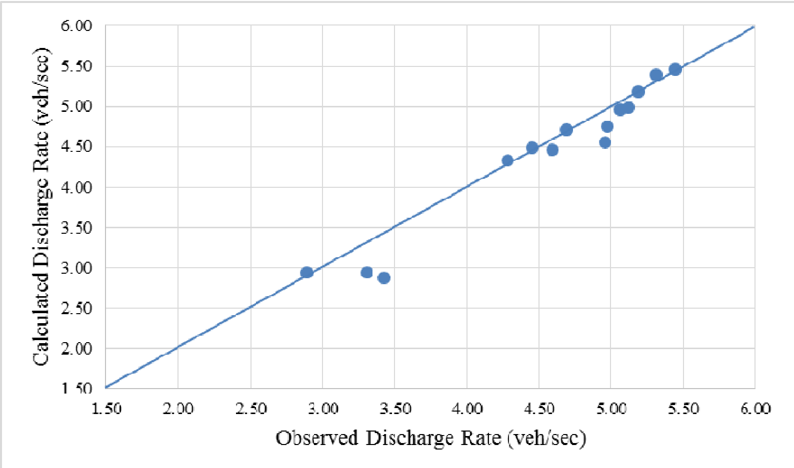

Figure 4.Results of validation of discharge rate model

7. Dynamic Saturation Flows

At signalized intersections, the queue discharge process is considered to be the principal portion of traffic behavior affecting the performance of the junction.Several studies have indicated in Table 12 that, the saturation flow is not a static value but it varies with roadway and traffic conditions. So, the term is indicated here, the ‘dynamic’ to express saturation flows for varied traffic conditions. The dynamic saturation flow values have been derived based on the observed geometric and traffic attributes at the approaches of the intersections. Table 11 provides saturation flow values based on validated model of discharge rate given in equation (9), in which width and composition of two-wheelers are varied. The higher arrival rate of 0.20 veh/sec per metre width have been considered as fixed input with variation in width from intermediate lane to 4-lane, and the percentage two-wheelers from 50% to 80%. The same is plotted in figure 5.

Table 11.Saturation Flow (vehcle/hour) values based on validated model

Width [*] *(m)* / *% (TW)*	*6.6*	*7.5*	*10.5*	*14*
50	13725 (3.81) [+]	14182 (3.94)	15705 (4.36)	17482 (4.86)
60	15129 (4.20)	15586 (4.33)	17109 (4.75)	18886 (5.25)
70	16533 (4.59)	16990 (4.72)	18513 (5.14)	20290 (5.64)
80	17937 (4.98)	18394 (5.11)	19917 (5.53)	21694 (6.03)

[*] Approach width, [+] Figures in brackets represent discharge rates (veh/sec)

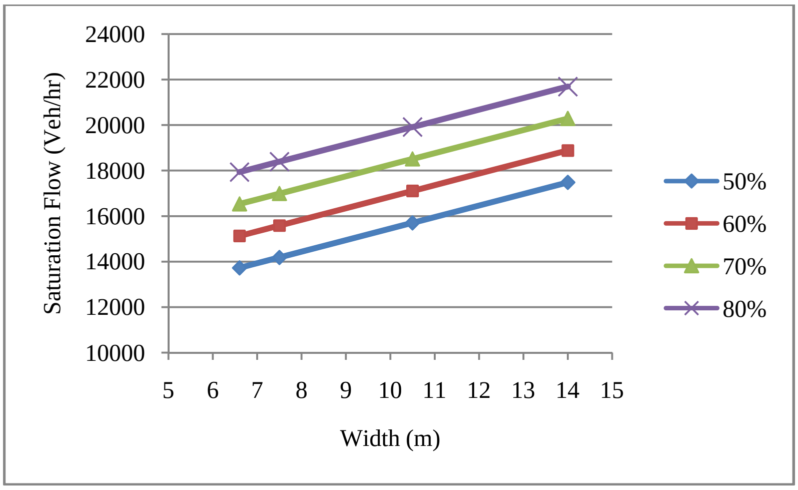

Figure 5.Saturation Flow with varied Width and %TW

A comparison between thederived saturation flow and saturation flow from earlier literatures is displayed in Table 12. It is observed from the Table 12 that,the saturation flow values varies extensively across the countries. This variation can be explained by the roadway and traffic conditions, control elements and the procedure used for the study. The variation of saturation flow is also observed by the studies in the same nation (UK and India). It may be noted that the saturation flows shown in this Table 12 are only representative and these values will vary with location and time.

Table 12. Comparison of previous saturation flow studies with present study

Sr. No.	*Organisation or Author*	*Country*	*Saturation Flow (PCU/hr)*
1	Indian Road Congress (IRC SP 41)	India	1890
2	US HCM 2010	USA	1900
3	IHCM 1997	Indonesia	600 PCU/m, 2160
4	Malaysia Highway Capacity Manual 2006	Malaysia	1930
5	[a]Wester and Cobbe (1966)	UK	1800
6	[a]Kimber et al. (1986)	UK	2080
7	[a]Branston (1979)	UK	1778
8	[a]Miler (1968)	Australia	1710
9	[a]Highway Engineering Laboratory (1990)	Athens, Greece	1972
10	[a]Huzayying and Shoukry (1986)	Egypt	1617
11	[a]Hussain (1990)	Malaysia	1945
12	[a]Coeymans and Meely (unpublished)	Chile	1603
13	[a]De Andrade (1998)	Brazil	1660
14	[a]Bhattacharya and Bhattacharya (1982)	India	1232
15	Vedagiri and Arasan (2006)	India	2196

Sr. No.	*Organisation or Author*	*Country*	*Saturation Flow (PCU/hr)*
16	Radhakrishna and Mathew (2011)	India	1925
17	Shao et al. (2011)	China	1800
18	**Present Study**	**India**	**2265**

[a]Turner and Harahap (1993)

8. Conclusions

The road traffic and travel situation is highly aggravated in metropolitan cities of developing country like India because of significant growth in traffic and addition of more and more numbers of vehicles year by year in to the stream with wide ranging static and dynamic characteristics. The PCU values are derived for different types of vehicles in the traffic stream by two different approaches namely, speed to area ratio and multiple linear regression approach. It is observed that PCU values of an individual vehicle are not constant as they vary with traffic situations, static and dynamic characteristics of vehicles, queue formation and queue discharge behavior at the approaches. The finding re-establishes the fact that the unified passenger car unit concept for different vehicles do not hold well for the mixed traffic condition. Saturation flow is a main factor in the signal design, and is depends on roadway and traffic conditions, which can vary substantially from one region to another.The saturation flow model recommended by HCM is mainly for homogeneous traffic conditions, with restricted capability to report heterogeneity.But the traffic in India is highly heterogeneous and hence, defining a unified saturation flow concept is a challenging task.Study indicates that saturation flow is not a fixed value unlike Webster’s saturation flow model or empirical formula 525*w* proposed by Indian Road Congress. On the contrary the saturation flow varies for the mixed traffic plying on Indian roads with references to the percentage of two wheelers. Therefore, with the presence of smaller size vehicles like two-wheelers, when they increase in the stream, saturation flow rises. Sensitivity analysis shows that, effect of arrival rate of vehicles is significant on saturation flow rate. So, arrival rate is equally important parameter for mixed traffic conditions. Validation results shows that the discharge flow estimated using the model is closer to field values, which implies that effects of arrival rate and two-wheelers are to be considered while modelling saturation flow in mixed traffic conditions.

References

Alam, J. B., Khalid, A. O., Hamid, O. A., Zahran, S. Z. (2011) "Signalized intersection capacity adjustment factors for Makkah, Saudi Arabia",*Canadian Journal of Transportation,* 4 (1), pp. 56-66.

Anusha, C. S., Verma, A., Kavitha, G. (2013) "Effects of two-wheelers on saturation flow at signalized intersections in developing countries",*Journal of Transportation Engineering,* 139 (5), pp. 448-457.

Arasan, T. V.,Jagadish, K. (1995) "Effect of heterogeneity of traffic on delay at signalized intersections",*Journal of Transportation Engineering,*121 (5), pp. 397-404.

Arasan, T. V.,Vedagiri, P. (2006) "Estimation of saturation flow of heterogeneous traffic using computer simulation",*Proceedings 20th European Conference on Modelling and Simulation,* ECMC, Bonn, Germany.

Bester, C.J., Meyers, W.L. (2007) "Saturation flow rates",*Proceedings of the 26th Southern African Transport Conference*, SATC, Pretoria, South Africa,pp. 560 -568.

Branston, D.M., Vanzuylen, J.H. (1978) "The estimation of saturation flow, effective green time and passenger car equivalents at traffic signals by multiple linear regression",*Transportation Research,* 12 (1-D), pp. 47 - 53.

Chandra, S. (2004) "Capacity estimation procedure for two lane roads under mixed traffic conditions",*Journal of Indian Road Congress,*165, pp. 139-170.

Hadiuzzaman, M., Rahaman, M.,Karim, A. (2008) "Saturation flow model at signalized intersection for non-lane based traffic",*Canadian Journal of Transportation,* 2 (1), pp. 77-90.

Hossain, M. (2001) "Estimation of saturation flow at signalized intersections of developing countries: a micro – simulation modelling approach",*Transportation Research Part A: Policy and Practice,*35(2), pp. 123-141.

Indian Roads Congress (IRC), (1994) "Guidelines for design of at-grade intersections in rural and urban areas",*IRC Special Publication, No. 41*, Indian Roads Congress, New Delhi, India.

Justo, C. E. G.,Tuladhar, S. B. S. (1984) "Passenger car unit values for urban roads",*Journal of the Indian Road Congress,*45, pp. 183-238.

Kimber, R. M., McDonald, M.,Hounsell, N. (1985) "Passenger car units in saturation flows: concept, definition, derivation",*Transportation Research – B,*198, pp. 39 -61.

Kockelman, K. M., Shabih, R. A. (2000) "Effect of light duty vehicle on signalized intersection",*Journal of Transportation Engineering,*126 (6), pp. 506–512.

Minh, C. C., Sano, K. (2003) "Analysis of motorcycle effects to saturation flow rate at signalized intersection in developing countries",*Journal of the Eastern Asia Society for Transportation Studies,*5, 1211-1222.

Patil, R. G., Roa, K. V. K., Xu, M. S. N. (2007) "Saturation flow estimation at signalized intersections in developing countries",*Proc., 86th Annual Meeting (CD-ROM)*, Transportation Research Board, Washington, DC.

Radhakrishnan P., Mathew T. V. (2011) "Passenger car units and saturation flow models for highly heterogeneous traffic at urban signalised intersections",*Transportmetrica,* 7 (2), pp. 141–162.

Road Research Laboratory (1963) "A method of measuring saturation flows at traffic signals",*Road Note 34,* HMSO, London.

Sun, H., Yang, J., Wang, L., Li, L., Wu, B. (2013) "Saturation flow rate and start-up lost time of dual-left lanes at signalized intersection in rainy weather condition",*13th COTA*

International Conference of Transportation Professionals, Elsevier,Shenzhen, China, pp. 270-279.

Transportation Research Board (2010) *Highway Capacity Manual*, Washington, D. C.

Turner, J., Harahap, G. (1993) “Simplified saturation flow data collection methods”, Crowthorne: *Transport Research Laboratory*, Technical Paper PA 1292/93.

Zhang G., Chen J. (2009) “Study on saturation flow rates for signalized intersections”,*International Conference on Measuring Technology and Mechatronics Automation*, IEEE, New York, pp. 598-601.